

The Ordovician–Silurian boundary in the United States

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Synopsis

Ordovician and Silurian rocks are widespread in the United States and there are numerous outcrops in many regions displaying the systemic boundary interval. However, a regional review of key sections in all the major outcrop areas shows that biostratigraphically closely controlled and stratigraphically complete or nearly complete boundary successions are quite rare. Indeed, the Esquibel Island section in south-eastern Alaska, where the systemic boundary is in a continuous graptoliferous sequence, is not only the only known occurrence in the United States of a typical *P. acuminatus* Zone fauna, but also the only known place in the country where the systemic boundary can be established precisely on graptolites in a continuous succession. Elsewhere, relatively complete, if not complete, boundary successions are present in the Appalachians and in the Great Basin, as well as Alaska, but in virtually all cases the biostratigraphical control is not good enough to establish the boundary level with certainty. Most of the sections in these regions display a gap in the boundary interval, and this is the case also in most of the many boundary sections in the Midcontinent region. The best known, and stratigraphically most nearly complete, cratonic sections are in Arkansas, Oklahoma, Missouri, and Illinois, where strata having a taxonomically varied *Hirnantia* fauna are overlain, with locally only a minor, if any, stratigraphical gap, by rocks containing Llandovery fossils. No graptoloid graptolites are known from these sections, and the precise level of the systemic boundary is uncertain in some sections. It is concluded that further studies are urgently needed on fossils and rocks in the boundary interval, particularly to establish the precise age of the conodont faunal turnover as well as to clarify the mutual relations between the distribution patterns in time and space displayed by different groups, and their relations to the graptolite-based systemic boundary.

Introduction

Ordovician rocks are present in the subsurface over much of the United States and they are exposed in several major regions (Cook & Bally 1975). Although less widespread than those of Ordovician age, Silurian rocks are likewise distributed over major parts of the country and exposed over considerable areas. Accordingly, it is not surprising that the interval of the Ordovician–Silurian systemic boundary is available for study at a large number of localities from the Appalachians in the east to the Great Basin in the west. In many of these sections, the faunal succession is incompletely known or fossils are absent in critical intervals, which applies to the cratonic areas in the continental interior as well as to the geosynclinal areas along the continental margins. Nevertheless, because in most sections, particularly the cratonic ones, the systemic boundary is associated with a stratigraphical gap and a change in lithology, its level in those sections can be readily recognized. As is the case elsewhere in the world, nearly complete successions in continuously fossiliferous facies across the boundary interval are quite rare in the United States both in shelly and graptolitic facies. For instance, we are not aware of a single section outside Alaska where the precise level of the base of the *P. acuminatus* Zone, that is the internationally accepted base of the Silurian, can be recognized by means of graptolites or other fossils. It is quite clear that the choice of this level for the systemic boundary at the present time makes its recognition difficult, if not impossible, in stratigraphically more or less complete successions like those in the Great Basin (Ross *et al.* 1979; Leatham 1985; etc.) and in the Mississippi Valley region (Amsden 1986).

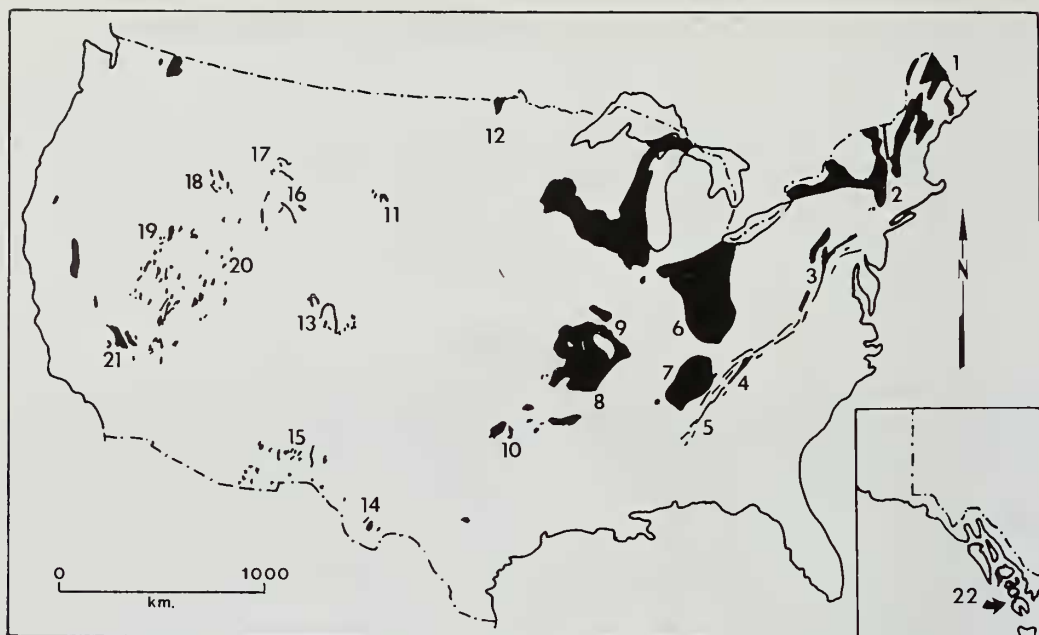


Fig. 1 Index map showing areas with Ordovician and/or Silurian outcrops (black) and systemic boundary sections. 1, northern Maine; 2, eastern New York and western Vermont; 3, central Appalachians (Pennsylvania and adjacent states); 4, eastern Tennessee; 5, Alabama and Georgia (southern Appalachians); 6, the Cincinnati region and adjacent areas in Ohio, Kentucky, and Indiana; 7, the Nashville dome in central Tennessee; 8, northern Arkansas (including the Batesville district); 9, eastern Missouri and southwestern Illinois; 10, southern Oklahoma (including the Arbuckle Mountains); 11, Black Hills (South Dakota and Wyoming); 12, North Dakota; 13, Colorado; 14, west Texas; 15, New Mexico; 16, Bighorn Mountains, Wyoming; 17, Montana; 18, Idaho; 19, Nevada; 20, Utah; 21, southeastern California; 22, southeastern Alaska (inset map).

The purpose of the present paper is to review briefly the biostratigraphy of the systemic boundary interval in key sections in the principal outcrop areas. Page limitations make it necessary to restrict ourselves to data essential for the understanding of the local and regional geology of this interval in the United States. For convenience, we will deal with each of the major outcrop regions separately, from the Appalachians in the east to the Great Basin in the west. For the location of these regions, see Fig. 1.

Northern Appalachians

In large parts of the Northern Appalachians in the United States (Maine to New York State), Silurian or younger rocks rest with a conspicuous, in many cases angular, unconformity on the Ordovician (Berry & Boucot 1970: fig. 6). This stratigraphical gap varies in magnitude both locally and regionally but includes in most cases portions of both the Ordovician and Silurian systems. Conventionally, this gap is explained as a product of the Middle to Late Ordovician Taconic orogeny, but it is evident that the apparently global drop in sea level during the latest Ordovician (Hirnantian) contributed to emergent conditions, at least locally.

In this region, biostratigraphical control through the systemic boundary interval is, in general, poor. This is partly due to the fact that the rocks were largely deposited in environments with small numbers of shelly organisms, and those that became fossilized were in many cases strongly affected by the subsequent metamorphism of the host rocks. That diagnos-

tic fossils are present locally is shown by Neuman's (1968) finds of shelly fossils of the *Hirnantia* fauna in east-central Maine, the only occurrences of this type of fauna from the northeastern United States. Another, and in terms of geology of the systemic boundary even more interesting, sequence is that of the Carys Mills Formation of northeastern Maine and adjacent New Brunswick. The lower part of this thick unit has yielded specimens of *Glyptograptus persculptus* (Rickards & Riva 1981) and Llandovery age graptolites are known from higher parts of the formation (Pavrides 1968). The Carys Mills has also produced well preserved conodonts of the *Icriodella discreta-I. deflecta* Zone of probable Rhuddanian (early Llandovery) age (Barnes & Bergström, this volume) but, unfortunately, the precise stratigraphical position of these conodonts within the formation is uncertain because of the scattered exposures, considerable thickness, monotonous lithology, and structural deformation of the unit. At any rate, it appears rather likely that the Carys Mills represents a stratigraphically complete succession from the uppermost Ordovician to the lower Silurian, but further studies are needed to pinpoint the level of the systemic boundary.

Central and Southern Appalachians

In southern New York and parts of eastern Pennsylvania and Virginia (Fig. 1), the Ordovician-Silurian boundary is marked by an unconformity (Dennison 1976) and parts of the Ordovician, and possibly also of the lowermost Silurian, are missing. From north-central Pennsylvania to eastern Tennessee, the systemic boundary is somewhere in a succession, several hundred metres thick, of near-shore to non-marine clastic sediments lacking shelly fossils of stratigraphical utility. Although the precise level of the systemic boundary remains undetermined in these successions, it has been common practice to classify the Juniata and Sequatchie formations as Ordovician and the overlying Tuscarora and Clinch formations as Silurian.

Recent work by Colbath (1986) has raised the possibility of establishing a viable palynomorph (acritarch and chitinozoan) biostratigraphy useful for precise recognition and correlation of the systemic boundary in these successions. Likewise, Gray's work (1985) on higher land plant spore tetrads permits recognition of the approximate boundary interval. Both the spore tetrads and the marine palynomorphs occur in some abundance in near-shore marine sediments. The spores are also found in purely non-marine facies provided they have not been destroyed by low-temperature metamorphism of the host strata. However, palynomorph work in the systemic boundary interval in this region has not passed the pioneer stage, and much additional study is needed to assess the local and regional biostratigraphic utility of these fossils.

In the southernmost Appalachians, in the Birmingham area of Alabama, the systemic boundary is marked by a conspicuous stratigraphical gap that includes the entire Upper Ordovician and probably the lowermost Llandovery as well (Hall, unpublished; Berry & Boucot 1970). Near the Alabama-Georgia boundary, the stratigraphical gap also includes the entire Middle Ordovician (Dennison 1976), but in northwesternmost Georgia, Chowns (1972) considered the systemic contact conformable on lithological evidence. The youngest Ordovician strata in much of Alabama, which are referred to the Sequatchie Formation (Drahovzal & Neathery 1971), are of Late Ordovician (Maysvillian and Richmondian) age. In Limestone County in northern Alabama, the Devonian Chattanooga Shale contains reworked Late Ordovician (probably Richmondian) conodonts (Bergström, unpublished) apparently originating from now-eroded rocks that may be younger than the biostratigraphically dated parts of the Sequatchie Formation. Where dated biostratigraphically, the Sequatchie is separated from overlying rocks by a stratigraphical gap corresponding not only to the uppermost Ordovician but also some part of the post-Ordovician succession. Locally this gap is substantial and may include more than a system.

Eastern North American Midcontinent

We include in this area the Cincinnati Arch region in Ohio, Kentucky, and Indiana, and the Nashville Dome area in central Tennessee (Fig. 1).

The Cincinnati region contains the Reference Standard of the North American Upper Ordovician, the Cincinnati Series. Both faunal and lithological evidence suggest an appreciable hiatus between the Ordovician and the Silurian over the entire outcrop area in the Cincinnati region. The stratigraphically most complete succession is apparently on the eastern side of the Cincinnati Arch in southern Ohio and adjacent Kentucky. There is no record of Hirnantian (latest Ordovician) age rocks anywhere in the Cincinnati region and the youngest Cincinnati stage, the Richmondian, is considered to be of pre-Hirnantian age. Based on the succession of Anticosti Island, Québec, Canada, Twenhofel's (1921) Gamachian Stage has in recent years been recognized as a post-Richmondian, pre-Silurian standard unit (Barnes & McCracken 1981). Although rocks of Gamachian age are not known to be represented in the Cincinnati type area, the Gamachian is now classified as the uppermost part of the Cincinnati Series (Ross *et al.* 1982).

One of the best exposed and most representative sections through the Ordovician–Silurian boundary interval on the eastern flank of the Cincinnati Arch is a series of exposures along Ohio Highway 41 between West Union and Ohio Brush Creek, Adams County, Ohio (Summerson 1963; Rexroad *et al.* 1965; Gray & Boucot 1972; Grahn & Bergström 1985). In this section, the beds are horizontal, developed in fossiliferous limestone and shale, and there are no structural complications. The topmost Ordovician unit, the Drakes Formation of Richmondian age, is overlain conformably and without conspicuous lithological break by the Belfast Member of the Brassfield Formation (Fig. 2). This unit has produced a relatively undiagnostic conodont fauna of general early Llandovery type (Rexroad 1967) as well as chitinozoans suggesting a *C. cyphus* Zone age (Grahn & Bergström 1985). Grahn & Bergström (1985) interpreted the stratigraphical gap as corresponding to about four graptolite zones and it is surprising that there is no channelling, development of a conglomerate, or other lithic evidence of a sedimentary break. The major body of the Brassfield, that is, its post-Belfast part, contains a rich megafossil fauna of early to middle Llandovery age (Berry & Boucot 1970) as well as a stratigraphically diagnostic conodont fauna of the *Distomodus kentuckyensis* Zone (Rexroad 1967; Cooper 1975) and chitinozoans (Grahn 1985). There are no graptolites known from this succession.

In many other Cincinnati region sections, especially on the west flank of the Cincinnati Arch, the stratigraphical gap associated with the systemic boundary is even greater than in the Ohio Brush Creek sections (Rexroad & Kleffner 1984).

In parts of the Nashville Dome in central Tennessee, the Devonian Chattanooga Shale unconformably overlies Middle Ordovician rocks (Dennison 1976). In other parts of the Nashville Dome, strata dated as Richmondian are overlain unconformably by the Brassfield Limestone of middle Llandovery age (Wilson 1949), which indicates the presence of a stratigraphical gap of magnitude similar to that in the Cincinnati region.

Central North American Midcontinent

We include in this area Oklahoma and adjacent Texas Panhandle, Arkansas, Missouri, Illinois, Minnesota, and Wisconsin (Fig. 1).

In a recent comprehensive study, Amsden & Barrick (1986) provided a useful summary of the geology of the Ordovician–Silurian boundary interval in this region. Of particular significance is the confirmation of the widespread occurrence of latest Ordovician strata having shelly fossils of the *Hirnantia* fauna and conodonts of the *Noixodontus* fauna. The stratigraphically most informative sections are in the Batesville district of north-central Arkansas and in eastern Missouri. Both locally and regionally, the stratigraphical succession varies a great deal, and in several cases, sections in close proximity to each other exhibit striking differences in lithological and stratigraphical development. This is well illustrated by the conditions in the Batesville district as well as in eastern Missouri.

In the Batesville district two sections are of particular interest. One of these sections is in the Love Hollow Quarry (Craig 1968, 1986a, 1986b; Amsden 1968, 1986). In this large and recently active quarry, the beds are horizontal and there are no notable tectonic complications. A

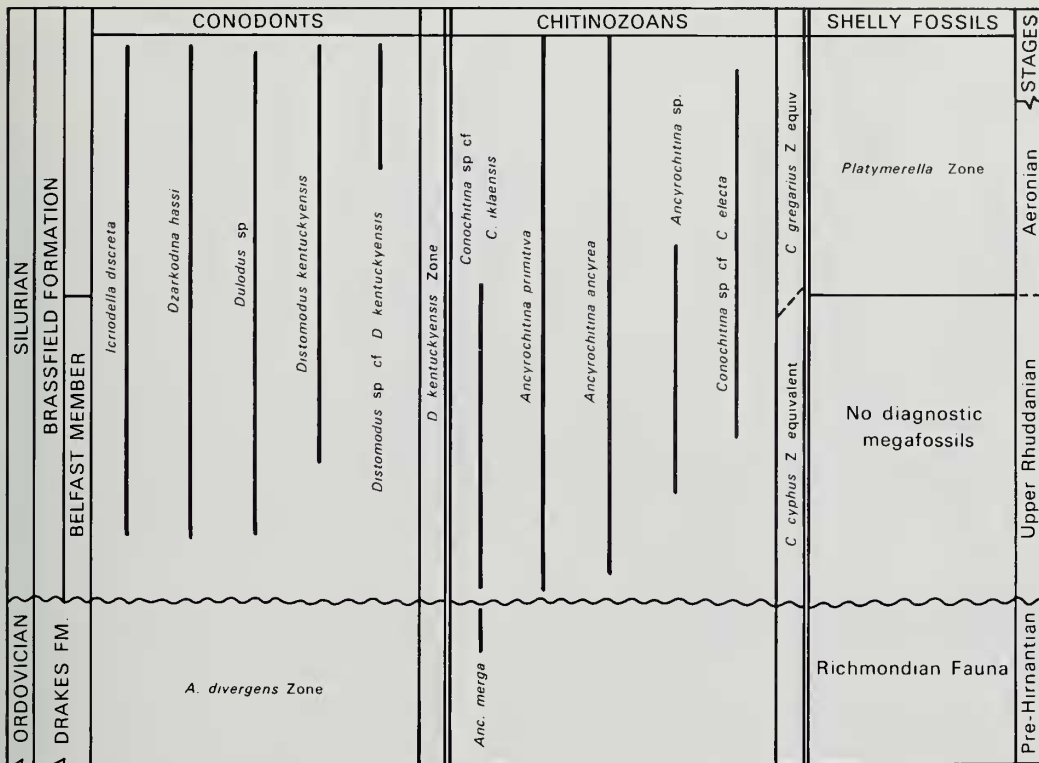


Fig. 2 Vertical ranges of selected conodont and chitinozoan species, and the occurrence of index megafossil assemblages, in the systemic boundary interval in exposures along Ohio Highway 41 northeast of West Union, Adams County, Ohio. Based on data from Berry & Boucot (1970), Cooper (1975), Grahn & Bergström (1985), and Grahn (1985). Note that there is a prominent stratigraphical gap between the Ordovician and the Silurian corresponding to the Hirnantian and the lower Rhuddanian. Although this gap is about four graptolite zones, there is very little lithological evidence of its existence in these sections.

stratigraphical column with fossil occurrences is given in Fig. 3. It should be noted that the Cason Oolite as well as the overlying *Triplesia alata* beds were developed in a large limestone lens which is now quarried away.

The Cason Oolite contains brachiopods that are used by Amsden (1986) for correlation with the Hirnantian Keel Limestone of Oklahoma. The oolite also contains conodonts of the *Noixodontus* fauna (Craig 1986a; Barrick 1986) that supports this correlation. The overlying pelmatozoan limestone, referred to by Amsden (1986) as the *Triplesia alata* beds and by Craig (1986b) as the Brassfield Limestone, contains late Llandovery brachiopods and conodonts (Craig 1986b). No graptolites have been found in this succession. The contact between the Cason Oolite and the overlying pelmatozoan limestone has been described as 'stylolitic' (Craig 1969). It appears to represent a stratigraphical gap but its exact magnitude is uncertain, although Barrick (1986) and Craig (1986b) report *O. celloni* Zone (late Llandovery) conodonts from the *Triplesia alata* beds at this locality.

A similar succession (Fig. 3) is reasonably well exposed 0.5 km NE of St. Clair Springs (Amsden 1986) in which the Cason Oolite, which contains a Hirnantian age brachiopod fauna similar to that of the Keel of Oklahoma and the Edgewood of Missouri, is directly overlain by about 3 m of crinoidal limestone classified as the Brassfield Limestone by Craig (1986b). The

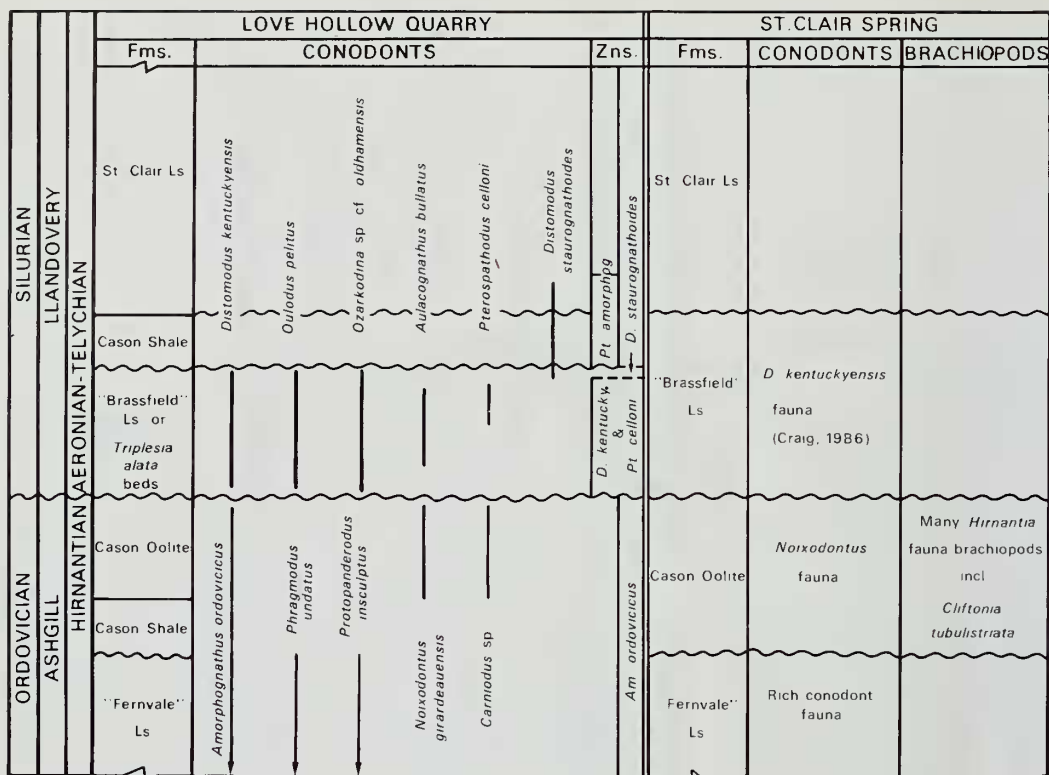


Fig. 3 Vertical ranges of important conodont species, and the occurrence of *Hirnantia* fauna brachiopods in two sections in the Batesville district, Arkansas. Based on Amsden (1986), Craig (1986a, 1986b), and Barrick (1986). Note that there is a conspicuous stratigraphical gap in the systemic boundary interval with a considerable portion of the Llandovery missing. The Love Hollow Quarry exposure of the Cason Oolite and the *Triplexia alata* beds is now quarried away (Amsden 1986).

conodonts from this locality confirm that the Cason Oolite is of Hirnantian age and that the overlying Brassfield is coeval with the Brassfield of the Cincinnati region (Craig 1986b; Barrick 1986). The systemic boundary is placed at the base of the Brassfield and is not strongly expressed lithologically; it may be associated with a stratigraphical gap corresponding to the lowermost Llandovery, but conodonts and other fossils do not provide sufficient stratigraphical resolution to assess its magnitude precisely.

The Cason Oolite equivalent in southern Oklahoma is apparently the Keel Limestone (Amsden 1986) that has yielded Hirnantian age brachiopods as well as conodonts of the *Noxodontus* fauna (Barrick 1986). Its topmost part has also produced stratigraphically younger conodonts of general Silurian aspect but no Silurian index species. Barrick assigned the latter fauna to the Llandovery and placed the systemic boundary within the Keel. Amsden, on the basis of his brachiopod studies, placed the entire Keel in the Ordovician (Amsden 1986: text-fig. 37) and noted that the unit is separated from the overlying Cochrane Formation by a large stratigraphical gap corresponding to the lower and middle Llandovery. In our opinion, the Silurian-type conodont fauna reported from the upper Keel by Barrick (1986) does not provide firm evidence of Silurian age because, as shown by Barnes & Bergström (this volume, p. 325), the turnover from an Ordovician-type to a Silurian-type conodont fauna may well have taken place in very latest Ordovician (late *G. persculptus* Zone) time, within a time interval older than

the base of the Silurian. Whether or not this alternative dating is correct can be solved only after the conodont faunal turnover has been firmly dated in terms of graptolite zones.

As noted by Amsden (1986), there are two important outcrop areas of the systemic interval in the Mississippi Valley, one in west-central Illinois and northeastern Missouri, and the other in southwestern Illinois and southeastern Missouri. A considerable number of sections through the uppermost Ordovician and overlying Silurian strata have been described by Amsden (1974, 1986) and Thompson & Satterfield (1975). The former also described the brachiopod faunas and the latter reported on the conodonts (also cf. McCracken & Barnes 1982). The stratigraphically most complete systemic boundary sequences are in the former area; in the latter area, the Edgewood Group, of Hirnantian age at the top, is overlain directly and unconformably by the Sexton Creek Limestone that contains brachiopods suggesting a late Llandovery (late Aeronian-Telychian) age (see Fig. 4).

One of the biostratigraphically most instructive sections is along the west side of Missouri Highway 79 at Clinton Springs at the south edge of Louisiana, Pike County, Missouri, where the horizontal beds are easily accessible along a major highway. Good brachiopod collections of Hirnantian age have been described from the Noix Oolite at this locality (Amsden 1974, 1986) and conodonts (of *Noixodontus* fauna type) studied by Thompson & Satterfield (1975). The overlying Bryant Knob Formation has yielded a few brachiopods (Amsden 1974) and conodonts interpreted as indicating early Llandovery age (Thompson & Satterfield 1975). The

		OKLAHOMA			S. E. MISSOURI		N. E. MISSOURI			
		Coal Creek			Thebes N.		Clarksville		4 mi S. of Clarksville	
ORDOVICIAN	ASHGILL	HIRNANTIAN	Keel Oolite	Hirnantia and Noixodontus faunas	Noix Oolite	Hirnantia and Noixodontus faunas	Noix Oolite	Noixodontus fauna	Noix Oolite	Hirnantia and Noixodontus faunas
			Ideal Quarry Mbr	D complanatus Z	Girardeau Ls	Orchard Creek Sh	Maquoketa Sh	Maquoketa Sh	Bryant Knob Fm	Hirnantia aspect conodonts
Sylvan Sh.	Undiagnostic conod. faunas									
SILURIAN	LLANDOVERY		U. Llandovery shelly & conodont faunas	Sexton Creek Fm	U. Llandovery brachiopods	Bowling Green Dolomite	Conodonts of Silurian aspect	Bowling Green Dolomite	Undiagn. brachs. Silurian-aspect conodonts	
?	?	?	P. celloni Z				? O. ? nathani Z			
			Amorphognathus ordovicicus ?		Amorphognathus ordovicicus Z.		Amorphognathus ordovicicus Z			

Fig. 4 Occurrence of key fossil assemblages, and general biostratigraphy, in the systemic boundary interval at some localities in Oklahoma, southeastern Missouri, and northeastern Missouri. For the location of these sections, see Amsden & Barrick (1986), and Thompson & Satterfield (1975), and these papers provide most of the data upon which this diagram is based. As is clear from the diagram, it is a review of the general stratigraphy in each of the areas and no correlation is implied between a unit in one column and one at the same vertical position in another column. In Oklahoma and southeastern Missouri, the systemic boundary is associated with a prominent stratigraphical gap whereas in the illustrated sections from northeastern Missouri, the succession across the systemic boundary may have only a minor, if any, stratigraphical gap.

succession does not show any distinct lithic break between these units and it may be one of the stratigraphically most nearly complete boundary successions in the Midcontinent region. A stratigraphically similar section is present along Highway 79 about 6.5 km south of Clarksville and about 19 km southeast of the Clinton Springs locality (Fig. 4; Amsden 1974). In his recent reassessment of the data at hand, Amsden again placed the systemic boundary at the top of the Noix Oolite but indicated (1986: 42) that 'the brachiopod biostratigraphy requires no significant interruption in the Noix-Bryant Knob sequence'. Interestingly, McCracken & Barnes (1982) reported conodonts of Silurian aspect, by them interpreted as representing either the *O.?* *nathani* Zone or the *D. kentuckyensis* Zone, from the lowermost 1.65 m of the Bowling Green Dolomite from a locality near Clarksville, where this unit directly overlies the Noix Oolite, which yielded a representative *Noixodontus* fauna. The conodont faunas from the Noix and the Bowling Green are quite different, and there is obviously a faunal turnover between these units. Unfortunately, as noted by Barnes & Bergström (this volume), the precise age of this faunal turnover is currently unknown in terms of the graptolite succession, but it is quite possible that it took place in the latest Ordovician. If so, it cannot be excluded that the systemic boundary is above the base of the Bowling Green. However, the fact that the latter unit is overlain by the late Llandovery Sexton Creek Limestone (Amsden 1986) makes it clear that the systemic boundary must be below the base of the latter unit.

Western Midcontinent

Important outcrop areas in this vast region (Fig. 1) include the Black Hills in South Dakota, the Bighorn Mountains in Wyoming, and areas in Montana, Colorado, southern New Mexico, and western Texas. Most of the Upper Ordovician in these areas consists of shallow-water carbonates with few megafossils but with taxonomically varied and biostratigraphically useful conodont faunas (Sweet 1979). The biostratigraphy of the overlying beds is less well known. No biostratigraphically well-controlled section is currently known that is stratigraphically reasonably complete in the Ordovician–Silurian boundary interval, and the data suggest that everywhere rocks of Ordovician age are separated from younger rocks by an unconformity representing a significant stratigraphical gap (Ross *et al.* 1982). The most nearly complete boundary section may be in the subsurface of North Dakota; however, data from the depositional basin extension in adjacent Manitoba, where the succession is quite similar to that in North Dakota, suggest the absence of at least the lowermost Llandovery (Barnes & Bergström, this volume).

Great Basin

We include in this region western Utah, Nevada, Idaho, and southern California (Fig. 1). There are numerous excellent sections of Upper Ordovician and Lower Silurian rocks in carbonate facies with virtually 100% exposure in the Great Basin, and most of these sections may be reached by car and by foot under reasonable conditions. However, many localities are structurally complex, and widespread secondary dolomitization, particularly in the Ordovician, makes it difficult to obtain well-preserved megafossils. Furthermore, diagnostic shelly megafossils are not common and graptolites are rare. Conodonts are known from some sections and they offer great potential for detailed stratigraphical work in the widespread carbonates; unfortunately, the problem of dating the conodont faunal turnover referred to above currently restricts their use in establishing precisely the position of the Ordovician–Silurian boundary. Accordingly, it is currently impossible to recognize with certainty the exact level of the systemic boundary, or even to assess whether or not deposition was continuous, at those carbonate sections where there is not a conspicuous unconformity in the boundary interval.

Much of the pertinent biostratigraphical information from megafossils was summarized by Berry & Boucot (1970). Additional data from shelly fossils have been published by, among others, Budge & Sheehan (1980*a*, 1980*b*) and Sheehan (1980, 1982).

Although conodont work in the systemic boundary interval is still in the pioneer stage in the Great Basin, it is apparent that conodonts offer greater potential than any other group for detailed biostratigraphical work. Two recent conodont studies deserve mention in a discussion of the systemic boundary. Ross *et al.* (1979) described the conodont biostratigraphy of the Hanson Creek Formation near Eureka, Nevada. They suggested that this unit represents continuous deposition from Ordovician to Silurian time. This is quite possible, but it is perhaps equally possible that all the conodont samples referred to in their study are of Ordovician age and that the systemic boundary is at a higher, as yet undetermined, level in the Hanson Creek than that advocated by Ross *et al.* because, as noted by Barnes & Bergström (this volume), none of their conodont collections contain index conodonts of definite Silurian age.

In another recent study, Leatham (1985) described the conodont biostratigraphy of the Fish Haven Dolomite and immediately overlying strata in a section in northernmost Utah. He identified a prominent conodont faunal turnover and a transitional fauna interval of 5.5 m thickness in the uppermost Fish Haven. The systemic boundary was placed at the base of this transition interval, but Leatham (1985) was uncertain whether or not there was a stratigraphical gap at this level. He was also uncertain about the nature of the mixed faunal association and suggested that it might be a product of reworking or stratigraphic leak. In our view, it cannot be excluded that the interval with the mixed fauna, regardless of its nature, is of Hirnantian age, and that the systemic boundary, as it is now defined by means of graptolites, is at a somewhat higher stratigraphical level, in the lowermost part of the Laketown dolomite.

Of special interest in a review of the Ordovician–Silurian boundary biostratigraphy in the Great Basin is Berry's (1986) record of an uppermost Ordovician to lower Silurian sequence of graptolite faunas in cherts and dolomites of the upper Hanson Creek Formation in the Monitor Range, central Nevada. A quartz sand-bearing dolomite, which evidently represents a period of shallowing near the end of the Ordovician, is underlain by strata having the *Dicellograptus complanatus ornatus* graptolite assemblage, and directly overlain by rocks containing the diagnostic species association of the *Glyptograptus persculptus* Zone. Stratigraphically higher beds contain species that may represent the *P. acuminatus* Zone but the zonal index has not been found.

Graptolite-bearing shale sequences of Ordovician and Silurian age are widespread in the mountain ranges in the Great Basin but the studied successions appear to be stratigraphically incomplete and display a gap in the systemic boundary interval. For instance, in the carefully studied and well-known graptolite shale succession in the Trail Creek area, central Idaho, Llandovery beds older than the *M. convolutus* Zone are missing (Carter & Churkin 1977).

Alaska

With one important exception, little information is currently available concerning the geology of the Ordovician–Silurian boundary in Alaska. This exception is the Prince of Wales region in southeastern Alaska (Fig. 1) where in the long-ranging Descon Formation there is a quite condensed succession through the systemic boundary interval, which displays a complete sequence of late Ordovician–early Silurian graptolite zones. The best known succession is on Esquibel Island (Churkin & Carter 1970; Churkin *et al.* 1971) where a few metres thick sequence of cherty shales spans the systemic boundary without any indication of depositional breaks. A less than 3 m thick interval with the *G. persculptus* Zone fauna is overlain by about 1.5 m of strata containing graptolites characteristic of the *P. acuminatus* Zone, including the zonal index. The Esquibel Island graptolite species associations show close similarity to those of coeval strata in the Birkhill Shale in the Ordovician–Silurian boundary stratotype at Dob's Linn in south Scotland, making it possible to recognize the level of the systemic boundary with considerable precision. This may be the only place in the United States where the level of the systemic boundary can be fixed conclusively on graptolite evidence in a stratigraphically continuous section, and one can only regret that this key locality is located in a remote region that is likely to be visited by very few geologists.

Conclusions

1. The Ordovician–Silurian boundary interval is well exposed at numerous localities throughout the United States from the Appalachians in the east to the Great Basin in the west.
2. Available biostratigraphical and/or lithostratigraphical evidence suggests that in the vast majority of these sections, there is a stratigraphical gap, of greatly different magnitude in different sections, in the boundary interval (Fig. 5). Particularly in the shallow-water cratonic successions, this gap reflects the global drop of sea-level near the end of the Ordovician, but there is evidence that local uplifts have been of importance in some areas. Currently, we are aware of only a single biostratigraphically closely controlled section in the United States, on Esquibel Island, southeastern Alaska, which displays continuous deposition throughout the boundary interval. However, such sections may exist elsewhere, particularly in the Appalachians and in the Great Basin.
3. Some of the best, and biostratigraphically most closely controlled, boundary sections are in Arkansas, Oklahoma, Missouri, and Illinois where rocks having the *Hirnantia* shelly fauna and the *Noixodontus* conodont fauna are overlain by Llandovery-age strata with, at least locally, only a minor, if any, stratigraphical gap. Regrettably, no stratigraphically diagnostic graptolites are known from these sections.
4. A considerable number of well-exposed, thick, and apparently stratigraphically relatively complete sections in shallow-water carbonate facies are known from the Great Basin. Dolomitization has seriously affected the state of preservation of the megafossils, which are rather scarce in most sections, but conodonts are moderately common and taxonomically varied. Yet, because the conodont biostratigraphy is not tied reliably to the graptolite zone succession in the *G. persculptus* and *P. acuminatus* Zones, currently the conodonts cannot be used to pinpoint the level of the systemic boundary in carbonate sections without a significant stratigraphical gap.
5. As far as we are aware, in the United States the *P. acuminatus* Zone has been identified with certainty only on Esquibel Island, Alaska, and this is the only place where the level of the systemic boundary can be established precisely by means of zonal graptolites. The successions of shelly fossils, conodonts and palynomorphs are thus far calibrated only imprecisely.

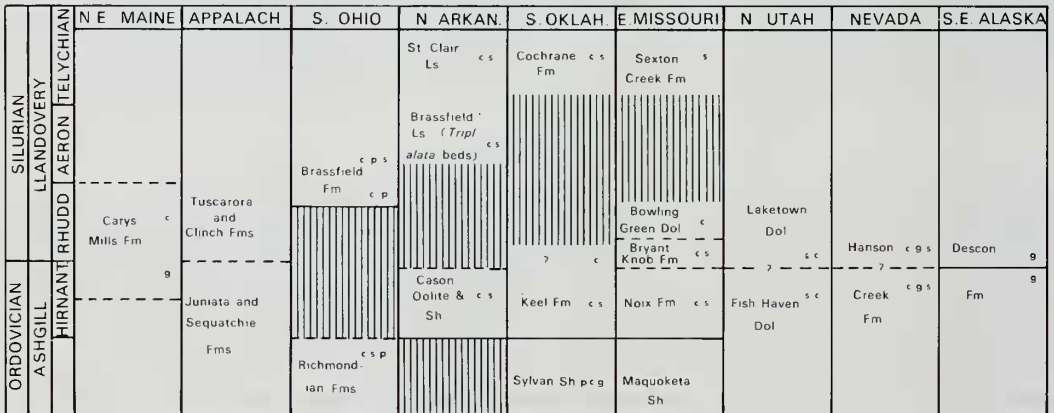


Fig. 5 Summary diagram showing important formations and degree of stratigraphical completeness of systemic boundary sections in nine important outcrop areas in the United States. Small letters, which indicate the presence of biostratigraphical control by means of a particular index fossil group, denote the following: c, conodonts; g, graptolites; s, shelly fossils (especially brachiopods); p, palynomorphs (especially chitinozoans). For further data on each of these successions, see the text. The section of northern Utah is that described by Leatham (1985). Vertical ruling marks proved or assumed stratigraphical gaps. Only formations near the systemic boundary are listed in the diagram.

cisely and broadly with the graptolite zone succession, and therefore these fossils cannot yet be used successfully to pinpoint the precise level of the Ordovician–Silurian boundary, especially in sections without a significant stratigraphical gap in the boundary interval. If the base of the *P. acuminatus* Zone is to be a viable and useful level for the base of the Silurian, then it is clearly necessary to determine the precisely equivalent level in the successions of shelly fossils, conodonts and palynomorphs. Because of the absence of graptolite control in the critical sections in the United States, that biostratigraphically most important correlation work will have to be carried out elsewhere in the world. However, the mutual stratigraphical relationships between non-graptolitic taxa are well displayed in sections in the United States. A detailed study of these relations no doubt will produce interesting and useful information of regional significance.

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